Appendix J - GPRA06 Vehicle Technologies Program

1. Introduction

The target markets for the Office of FreedomCAR and Vehicle Technologies (FCVT) program include light vehicles (cars and light trucks) and heavy vehicles (trucks more than 10,000 pounds Gross Vehicle Weight). Each will be discussed separately below.

1.1 Target Market: Alternate Technology Light Vehicle (ATV) Market

The alternate technology light vehicles (ATVs) included in the FCVT program are gasoline hybrid vehicles, diesel hybrid vehicles, and advanced diesel vehicles. The market for these technologies includes all cars and light trucks sold for both personal and business use. Today, the size of this market is approximately 17 million vehicle sales per year. Total car and light truck stock is about 220 million vehicles. EIA projects both sales and stock to grow to more than 20 million and 300 million respectively by 2025. Additional growth is expected post-2025.

1.2 Key Factors in Shaping the Market Adoption of ATVs

Key factors associated with the adoption of new vehicle technologies include how the new vehicle technologies compare with the baseline vehicle technologies in terms of the following vehicle attributes:

- Vehicle Price
- Fuel Economy
- Range
- Maintenance Cost
- Acceleration
- Top Speed
- Luggage Space

Of these, vehicle price and fuel economy are the most important.

Nonvehicle attributes that are important factors in a consumer's decision to purchase new vehicle technologies include the following:

- Fuel Price
- Fuel Availability

1.3 Methodology and Calculations

The factors listed above include the factors used in the modeling of new vehicle technology penetration by the NEMS and MARKAL models. ATV attributes and other factors are discussed below.

1.3.1 ATV Attributes

ATV attributes were developed based on the FCVT program goals, discussions with FCVT program managers, Powertrain Systems Analysis Toolkit (PSAT) modeling and payback analysis (Refs. 1-3). The PSAT model is a simulation model used by DOE to evaluate the fuel economy and performance of light vehicles using various technologies. Payback analysis was used to estimate what the incremental price of ATVs would be when they become cost competitive with conventional vehicles, a goal of the program. (The incremental price equals the present value of the energy cost reduction achieved by ATVs over three years, assuming a fuel price of $1.50/gallon gasoline equivalent and 7.5% discount rate.) Other attributes were based on a review of past GPRA characterizations (e.g., Ref. 4).

Because the NEMS and MARKAL models require different levels of detail, two separate vehicle characterizations are provided. In both cases, most of the attributes are provided as ratios to the vehicle attributes of conventional vehicles. (For NEMS, the $ value of the price increments were provided.) The attributes are for new vehicles in the year listed. **Table 1** contains the vehicle attributes for ATVs provided for input to the NEMS model. Attributes are provided for all six car size classes and six light truck classes that NEMS uses.

Table 2 contains vehicle attributes for ATVs provided as input to the MARKAL model. MARKAL uses only vehicle price and fuel economy attributes. MARKAL does not disaggregate cars and light trucks into various classes.

1.3.2 Fuel Price and Availability

Fuel price assumptions are discussed in **Chapters 4 and 5**. Gasoline and diesel fuel are assumed to be widely available.

1.3.3 ATV Market-Penetration Methodology

Brief descriptions of how the NEMS and MARKAL models each project new vehicle technology penetration using these vehicle attributes can be found in **Chapter 4** (NEMS) and **Chapter 5** (MARKAL).

1.4 Sources

1. “Strategic Plan,” U.S. Department of Energy Efficiency and Renewable Energy, DOE/GO-102002-1649 (October 2002).

2. Phillip Sharer and Aymeric Rousseau, “Fuel Economy of Advanced Technology Vehicles” for Phil Patterson, DOE (June 17, 2004).

3. Payback model developed by Jim Moore, TA Engineering (2003).

4. “Program Analysis Methodology: Office of Transportation Technologies, Quality Metrics 2003 Final Report”, prepared by OTT Analytic Team, for Office of Transportation Technologies, U.S. Department of Energy (March 2002).

Table 1. ATV Attributes Input to NEMS

	2-SEATER				MINI-COMPACT				SUB-COMPACT				COMPACT			
Advanced Diesel	**2014**	**2019**	**2024**	**2025**	**2018**	**2023**	**2025**	**N/A**	**2012**	**2017**	**2022**	**2025**	**2011**	**2016**	**2021**	**2025**
Incremental Vehicle Price	1341	988	853	867	1278	946	900		1089	828	718	741	1160	841	728	766
Range	1.20	1.20	1.20	1.20	1.20	1.20	1.20		1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20
Maintenance Cost	1.00	0.90	0.90	0.90	0.90	0.90	0.90		0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	1.00	1.00	1.00	1.00	1.00	1.00	1.00		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Luggage Space	1.00	1.00	1.00	1.00	1.00	1.00	1.00		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fuel Economy	1.50	1.60	1.70	1.72	1.50	1.60	1.64		1.50	1.60	1.70	1.76	1.50	1.60	1.70	1.78
Diesel Hybrid	**2016**	**2021**	**2025**	**N/A**	**2020**	**2025**	**N/A**	**N/A**	**2016**	**2021**	**2025**	**N/A**	**2014**	**2019**	**2024**	**2025**
Incremental Vehicle Price	1787	1380	1154		1999	1333			1413	1157	935		1433	1162	930	923
Range	1.25	1.25	1.25		1.25	1.25			1.25	1.25	1.25		1.25	1.25	1.25	1.25
Maintenance Cost	1.05	1.05	1.05		1.05	1.05			1.05	1.05	1.05		1.05	1.05	1.05	1.05
Acceleration	1.00	1.00	1.00		0.90	0.90			0.90	0.90	0.90		0.90	0.90	0.90	0.90
Top Speed	1.00	1.00	1.00		0.90	0.90			0.90	0.90	0.90		0.90	0.90	0.90	0.90
Luggage Space	0.95	0.95	0.95		0.95	0.95			0.95	0.95	0.95		0.95	0.95	0.95	0.95
Fuel Economy	1.80	2.10	2.12		2.09	2.12			1.70	2.10	2.12		1.70	2.08	2.11	2.12
Gasoline Hybrid	**2012**	**2018**	**2023**	**2025**	**2011**	**2016**	**2021**	**2025**	**2010**	**2014**	**2019**	**2025**	**2007**	**2012**	**2017**	**2025**
Incremental Vehicle Price	1508	1248	1035	1046	1437	1195	1004	1019	1286	1047	858	867	1305	1062	861	882
Range	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25
Maintenance Cost	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	1.00	1.00	1.00	1.00	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Luggage Space	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Fuel Economy	1.60	1.90	2.00	2.02	1.60	1.90	1.99	2.02	1.60	1.90	1.97	2.02	1.60	1.90	1.95	2.02

Table 1 (continued)

	MEDIUM CAR				LARGE CAR			
Advanced Diesel	**2010**	**2015**	**2020**	**2025**	**2009**	**2014**	**2019**	**2025**
Incremental Vehicle Price	1119	845	748	811	1208	898	794	860
Range	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20
Maintenance Cost	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Luggage Space	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fuel Economy	1.40	1.50	1.60	1.70	1.40	1.50	1.60	1.70
Diesel Hybrid	**2014**	**2019**	**2024**	**2025**	**2014**	**2019**	**2024**	**2025**
Incremental Vehicle Price	1319	1267	1075	1078	1409	1154	1141	1144
Range	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25
Maintenance Cost	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05
Acceleration	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Top Speed	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Luggage Space	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Fuel Economy	1.50	2.00	2.17	2.21	1.50	1.75	2.17	2.21
Gasoline Hybrid	**2006**	**2011**	**2016**	**2025**	**2009**	**2014**	**2019**	**2025**
Incremental Vehicle Price	1119	950	886	1014	1409	1010	941	1023
Range	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25
Maintenance Cost	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05
Acceleration	1.00	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Top Speed	0.90	0.90	0.90	0.90	1.00	0.90	0.90	0.90
Luggage Space	0.85	0.95	0.95	0.95	0.85	0.95	0.95	0.95
Fuel Economy	1.40	1.60	1.80	2.06	1.50	1.60	1.80	1.96

Table 1 (continued)

	MINIVAN				LARGE VAN			
Advanced Diesel	**2008**	**2013**	**2018**	**2025**	**2006**	**2011**	**2016**	**2025**
Incremental Vehicle Price	1226	931	822	883	1668	1204	1149	1080
Range	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20
Maintenance Cost	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Luggage Space	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fuel Economy	1.40	1.50	1.60	1.70	1.40	1.50	1.70	1.70
Diesel Hybrid	**2013**	**2018**	**2023**	**2025**	**2012**	**2017**	**2022**	**2025**
Incremental Vehicle Price	1430	1241	1149	1138	1946	1605	1480	1391
Range	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25
Maintenance Cost	1.09	1.05	1.05	1.05	1.09	1.05	1.05	1.05
Acceleration	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Top Speed	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Luggage Space	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Fuel Economy	1.50	1.80	2.10	2.13	1.50	1.80	2.13	2.13
Gasoline Hybrid	**2009**	**2014**	**2019**	**2025**	**2010**	**2015**	**2020**	**2025**
Incremental Vehicle Price	1226	1150	1039	1072	1668	1487	1394	1311
Range	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25
Maintenance Cost	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05
Acceleration	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Top Speed	0.75	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Luggage Space	0.90	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fuel Economy	1.40	1.70	1.90	2.00	1.40	1.70	2.00	2.00

Table 1 (continued)

	SMALL SUV				LARGE SUV				SMALL TRUCK				CARGO (Incl. 2b) TRUCK			
Advanced Diesel	**2008**	**2013**	**2018**	**2025**	**2007**	**2012**	**2017**	**2025**	**2008**	**2013**	**2018**	**2025**	**2006**	**2011**	**2016**	**2025**
Incremental Vehicle Price	1155	896	800	868	1563	1163	1019	1074	1112	859	764	830	1457	1089	962	1011
Range	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20
Maintenance Cost	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Luggage Space	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fuel Economy	1.35	1.45	1.55	1.65	1.35	1.45	1.55	1.65	1.35	1.45	1.55	1.65	1.35	1.45	1.55	1.65
Diesel Hybrid	**2011**	**2016**	**2021**	**2025**	**2015**	**2020**	**2025**	**N/A**	**2012**	**2017**	**2022**	**2025**	**2016**	**2021**	**2025**	**N/A**
Incremental Vehicle Price	1485	1283	1098	1169	2024	1665	1399		1425	1239	1050	1118	1874	1558	1368	
Range	1.20	1.20	1.20	1.20	1.20	1.20	1.20		0.90	0.90	0.90	0.90	0.90	0.90	0.90	
Maintenance Cost	1.05	105	1.05	1.05	1.05	1.05	1.05		1.05	1.05	1.05	1.05	1.05	1.05	1.05	
Acceleration	0.90	0.90	0.90	0.90	0.90	0.90	0.90		0.90	0.90	0.90	0.90	0.90	0.90	0.90	
Top Speed	1.00	1.00	1.00	1.00	1.00	1.00	1.00		0.90	0.90	0.90	0.90	0.90	0.90	0.90	
Luggage Space	1.00	1.00	1.00	1.00	1.00	1.00	1.00		0.80	0.90	0.90	0.90	0.80	0.90	0.90	
Fuel Economy	1.50	1.80	1.95	2.13	1.50	1.80	1.95		1.50	1.80	1.95	2.13	1.50	1.80	1.92	
Gasoline Hybrid	**2007**	**2012**	**2017**	**2025**	**2008**	**2013**	**2018**	**2025**	**2010**	**2015**	**2020**	**2025**	**2010**	**2015**	**2020**	**2025**
Incremental Vehicle Price	1155	962	966	1102	1563	1249	1231	1363	1112	922	923	1054	1457	1169	1162	1283
Range	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25
Maintenance Cost	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05
Acceleration	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Top Speed	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Luggage Space	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.80	0.95	1.00	1.00	0.80	0.95	1.00	1.00
Fuel Economy	1.35	1.50	1.75	2.00	1.35	1.50	1.75	2.00	1.35	1.50	1.75	2.00	1.35	1.50	1.75	2.00

Table 2. ATV Attributes for Input to MARKAL

Ratios to Conventional Vehicles

		2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
CARS											
Advanced Gasoline	MPG	1.0	1.0	1.01	1.02	1.03	1.025	1.02	1.015	1.01	1.01
	Incremental Price	1.0	1.01	1.05	1.09	1.24	1.25	1.25	1.25	1.25	1.25
Diesel	MPG	1.3	1.4	1.5	1.6	1.7	1.8	1.8	1.8	1.8	1.8
	Incremental Price	1.07	1.05	1.03	1.03	1.03	1.025	1.02	1.02	1.02	1.02
Gasoline HEV	MPG	1.3	1.5	1.7	1.96	2.06	2.22	2.22	2.22	2.22	2.22
	Incremental Price	1.1	1.07	1.05	1.045	1.04	1.03	1.02	1.02	1.02	1.02
Diesel HEV	MPG	NA	1.6	1.8	2.05	2.21	2.36	2.36	2.36	2.36	2.36
	Incremental Price	NA	1.1	1.08	1.075	1.07	1.055	1.04	1.035	1.03	1.03
LIGHT TRUCKS											
Advanced Gasoline	MPG	1.0	1.01	1.02	1.03	1.03	1.025	1.02	1.015	1.01	1.01
	Incremental Price	1.0	1.05	1.17	1.23	1.36	1.37	1.37	1.37	1.37	1.37
Diesel	MPG	1.3	1.35	1.4	1.5	1.65	1.7	1.8	1.8	1.8	1.8
	Incremental Price	1.06	1.04	1.035	1.03	1.025	1.02	1.02	1.02	1.02	1.02
Gasoline HEV	MPG	1.3	1.4	1.7	1.85	2	2	2	2	2	2
	Incremental Price	1.1	1.07	1.05	1.045	1.04	1.03	1.02	1.02	1.02	1.02
Diesel HEV	MPG	NA	1.5	1.8	1.9	2.13	2.13	2.13	2.13	2.13	2.13
	Incremental Price	NA	1.1	1.08	1.075	1.07	1.055	1.04	1.035	1.03	1.03

2.0 Heavy Vehicle Benefits Analysis Introduction

The following sections describe the approach to estimating benefits and analysis results for the Heavy Vehicle Technologies activities of the FreedomCAR and Vehicle Technologies Program of EERE. The scope of the effort includes:

- Characterizing baseline and advanced technology vehicles for Class 3–6 and Class 7 and 8 trucks,
- Identification of technology goals associated with the DOE EERE programs,
- Estimating the market potential of technologies that improve fuel efficiency and/or use alternative fuels,
- Determining the petroleum savings associated with the advanced heavy vehicle technologies.

In FY05, the Heavy Vehicles program activity expanded its technical involvement to more broadly address various sources of energy loss as compared to focusing more narrowly on engine efficiency and alternative fuels. This broadening of focus has continued in the activities planned for FY06. These changes are the result of a planning effort that occurred during FY04 and FY05 (Ref. 1).

This narrative describes characteristics of the heavy truck market as they relate to the analysis and provides a description of the analysis methodology—including a discussion of the models used to estimate market potential and benefits. The market penetration of advanced heavy vehicle technologies estimated here is then modeled as part of the EERE-wide integrated analysis (using NEMS and MARKAL) to provide final benefit estimates reported in the FY06 Budget Request.

2.1 Target Market: Heavy Vehicle Target Market

"Heavy Vehicles" are defined in this analysis as including Classes 3 through 6 (Medium Trucks) and Classes 7 and 8 (Heavy Trucks). The Heavy Truck classes are further subdivided by end-use types: i.e., Long-Haul, Intermediate, and Local Use. Vehicle Inventory and Use Survey (VIUS) data were examined for all vehicles in use and vehicles 2 years old or less (Ref. 2). The Heavy Truck vehicle market was then disaggregated into these three end-use types. The specific vehicle configurations grouped in each of the three types have similar usage and annual vehicle mile usage patterns. The vehicle type segments are made up of the vehicle configurations listed below:

- Local Use (Type 1) – multistop, step van, beverage, utility, winch, crane, wrecker, logging, pipe, garbage collection, dump, and concrete delivery;
- Intermediate Use (Type 2) – platform, livestock, auto transport, oil-field, grain, and tank;
- Long-Haul (Type 3) – refrigerated van, drop frame van, open top van, and basic enclosed van.

The lower speed and "stop and start" duty characteristics of Type 1 trucks greatly reduce the potential efficiency benefits in that sector compared to Types 2 and 3. For similar reasons, fuel

economy improvements due to other speed-dependent measures such as improved tires will have lower benefit here than in the other two types.

As compared to long distance, over the road travel, Type 2 vehicles tend to be used in a mix of local and regional delivery; and, as a result, will also realize greater fuel economy benefit from aerodynamic improvements than Type 1, but not as great as Type 3. Distances traveled by Type 2 vehicles are typically greater than Type 1, which infers that the typical speeds are higher. These characteristics make them a somewhat better market sector for measures that perform in relation to speed such as advanced tires. In general, Type 3 vehicles are the best candidates for technologies that reduce drivetrain or vehicle losses.

Refueling characteristics; i.e. central-source refueling or noncentral source also are considered in the market characteristics, as centrally refueled vehicles would find an alternative fuel source more practical than vehicles that always refuel at road-side facilities.

Eleven travel distance categories for medium trucks and 21 for heavy trucks are represented in the model. These categories were determined using travel distributions developed with the VIUS data by ORNL (Refs. 2, 3).

Exhibit 1 shows the distribution of annual travel for Class 3 through 6 and the three types of Class 7 and 8 vehicles. Type 3 vehicles display the greatest amount of annual travel of all heavy vehicle classes as is evidenced in part by the curve's peaking in the 120,000- to 139,000-mile segment.

Exhibit 2 shows the vehicle use pattern for Local or Type 1 Heavy trucks. The distribution based both on vehicles and vehicle-miles traveled are indicated.

The contrast in distribution by type is evident when Exhibits 2 and 3 are compared. **Exhibit 3** shows the same information as **Exhibit 2**—but for Type 3 trucks. For Type 1, the distribution peaks in the 20,000- to 39,000-mile segment. For Type 3, the peak distribution shows annual travel of 100,000 miles greater than Type 1—120,000 to 139,000 miles.

Centrally refueled and noncentrally fueled vehicle use characteristics also have been analyzed. Centrally refueled travel less per year than noncentrally refueled vehicles. In the noncentrally refueled vehicle segment, the majority of travel occurs from 100,000 to 140,000 miles per year. In the central refueling segment, the majority of travel occurs in a more even distribution between 20,000 and 140,000 miles per year.

Heavy vehicle market characteristics that are pertinent to the analysis are summarized in **Exhibit 4.** In the medium truck market segment (Classes 3 through 6), all vehicle types, with the exception of auto transport, on average travel about 20,000 miles per year. Heavy trucks, depending on type, travel an average of 40,000 miles to 92,000 miles per year. Based on discussions with program personnel, the baseline fuel economy for Type 3 heavy vehicles was changed to 7.5 MPG, a reduction from prior years. The fuel economy of this market sector remains significantly higher than that attributed to Type 1 heavy vehicles (7.5 vs. 4.55 MPG).

2.2 Key Factors Shaping Market Adoption of Technology

Based on a survey conducted by the American Trucking Associations in 1997, energy-conservation purchase decisions for this sector are significantly affected by economic viability—specifically the payback of the investment (Ref. 4). The survey of 224 motor carriers revealed that paybacks of one to four years were acceptable for energy-conserving technologies. Based on those findings, we model the market acceptance of the various technologies based on payback performance.

The Environmental Protection Agency has initiated regulation of emissions from Heavy Trucks. This is changing engine technology and diesel fuel refining. Some reduction in fuel economy with the new engines is also expected as the combustion process optimization is addressing reduction of emissions. These changes will impose both operating and capital costs on truck operators.

2.3 Methodology and Calculations

The analysis of the benefits expected from achieving the Heavy Vehicle technologies program goals was developed based on four primary reference sources:

- Technology energy efficiency and fuel-use characteristics—as provided by the managers of the technology programs;
- Vehicle characteristics and use information—as obtained from the 1997 VIUS. This provides information on both vehicle performance characteristics, such as fuel economy, and vehicle-use patterns such as miles traveled per year (Ref. 2);
- Truck operator investment requirements—as provided by a survey of Owner-Operators performed by the American Trucking Associations in 1995 (Ref. 4);
- Important "background" information such as energy prices and baseline technology fuel economies—as provided in the Annual Energy Outlook (Reference Case) prepared by the Energy Information Administration (Ref. 5).

The methodology involves the definition of the energy conservation or displacement and cost attributes of the advanced technologies being fostered by the program, the characterization of the markets affected, and the estimation of the benefits. Several models are used. Specifically, initial benefits estimates are generated through the linkage of four spreadsheet models:

- HTEB - Heavy Truck Energy Balance Model
- TRUCK 2.0 - Heavy Vehicle Market Penetration Model
- VISION 2.0, and
- Heavy Truck Summary (HVS) report generator.

The relationship of these four models is indicated in **Exhibit 5.**[1] Cost estimates are developed separately.

The **Heavy Truck Energy Balance Model** (HTEB) was developed to assess the overall fuel economy effect of several changes to the vehicle involving both the engine and other elements of the vehicle. It takes into account energy losses based on user selected inputs of vehicle use. It is a steady-state model. It was required as a result of the lack of existence of publicly available vehicle simulation tool. The fuel economies of new advanced heavy vehicle technologies estimated with the HTEB model are presented in **Exhibit 6.**

The cost estimates for these vehicles are also presented in **Exhibit 6.** The first cost of a technology is assumed to reduce to a two-year payback level as a program goal. As an example, the cost schedule for the **Exhibit 6** technologies in the Long Haul vehicle application is indicated in **Exhibit 7**. This process was replicated for Type 1 and Type 2 vehicles and Medium Trucks to develop similar cost estimates.

The values for fuel economy improvement from HTEB and cost are then input to **TRUCK 2.0.** This model was developed to estimate the potential market impacts of new technologies on the medium and heavy truck market. The results generated by this model are:

- Market penetrations, in units of percent of new vehicles sold for each type and class of vehicle, and
- Composite fuel economy rating (new mpg) of the vehicles sold, for each truck type.

As discussed, the TRUCK 2.0 model estimates market penetration based on cost effectiveness of the new technology. Cost effectiveness is measured as the incremental cost of the new technology less the expected energy savings of that technology over a specified time period in relation to specified payback periods**.**

Exhibit 8 shows the payback distribution assumed in the TRUCK model. This payback distribution was generated from the American Trucking Association's survey described above (Ref. 4). The survey found that, for example, 16.4% of the truck operators responding require a payback of one year on an investment. The TRUCK model market penetration calculation method for Class 7 and 8, Type 1 vehicles is described in **Exhibit 9.**

Th**e** market penetration results are supplied through a link to the **VISION 2.0** model (Ref. 6). The VISION model is used to estimate preliminary or first order oil/energy use and CO_2 emissions from highway vehicles through 2050. It contains a baseline estimate of heavy vehicle energy use to 2050. Through 2025 that baseline is the same as that of the AEO. By inputting the

[1] The HTEB was developed by William Shadis and James Moore of TA Engineering. The TRUCK (2.0) Model was developed as a collaborative effort, initially by John Maples of Oak Ridge National Laboratory (ORNL), with assistance from James Moore, of TA Engineering, Inc. Subsequent enhancements have been performed by Moore (TA Engineering). The Vision (2.0) model was developed by Margaret Singh and Anant Vyas of ANL. The Heavy Truck Summary Model is a report generating spreadsheet. It was initially developed by Maples, and has subsequently been modified by Analysts at the National Renewable Energy Laboratory, and TA Engineering.

market penetration and fuel economy of the advanced heavy vehicle technologies into the model, an alternative estimate of future heavy vehicle energy use is generated and benefits relative to the baseline can be estimated.

Since VISION does not disaggregate Types 1-3 Heavy Trucks or Hybrid-Non-hybrid Medium Trucks, the fuel economy multipliers generated by Truck 2.0 are aggregated on both a sales and VMT-weighted basis for input to VISION. These aggregated fuel economy multipliers are provided in **Exhibit 10**. They are also adjusted to take into account differences in baseline fuel economies provided in VIUS (used in TRUCK 2.0) and the AEO (used in VISION). These factors and the market penetration estimates also presented in Exhibit 10 are the factors ultimately used in the EERE-wide integrated analysis.

Finally, the **Heavy Truck Summary** report generator summarizes the first order benefits for the period covering 2000 through 2050. Benefits include the following:

- Heavy Truck Petroleum Use and Savings, by Class 3-6 and Class 7-8, Million BPD
- Heavy Truck Petroleum Savings - %
- Class 7&8 Truck Savings by Program Element (Technology), Million BPD
- Local Use Truck Savings by Program Element (Technology), Million BPD
- Intermediate Truck Savings by Program Element (Technology), Million BPD
- Long-Haul Truck Savings by Program Element (Technology), Million BPD.

These first order benefits have been generated and will be reported in a forthcoming report.

2.4 Sources

1. FreedomCAR and Vehicle Technologies R & D Plan (Draft), August 22, 2003.
2. "1997 Vehicle Inventory and Use Survey," EC97TV-US U.S. Bureau of the Census, Washington, D. C., 1999.
3. Personal Communication with Stacy Davis, ORNL, November 2001
4. "1997 Return on Investment Survey," American Trucking Association, Arlington Va., 1997.
5. "Annual Energy Outlook 2004, With Projections to 2030," Energy Information Agency, Department of Energy, Washington, D. C., (Web site address: http://www.eia.doe.gov/bookshelf.html *Library/Archives-Forecasting)*.
6. Singh, M.; A. Vyas, and E. Steiner, "VISION Model: Description of Model Used to Estimate the Impact of Highway Vehicle Technologies and Fuels on Energy Use and Carbon Emissions to 2050," ANL/ESD/04-1 (Dec. 2003).

Exhibit 1: Annual Miles Traveled for Four Truck Categories, 1997

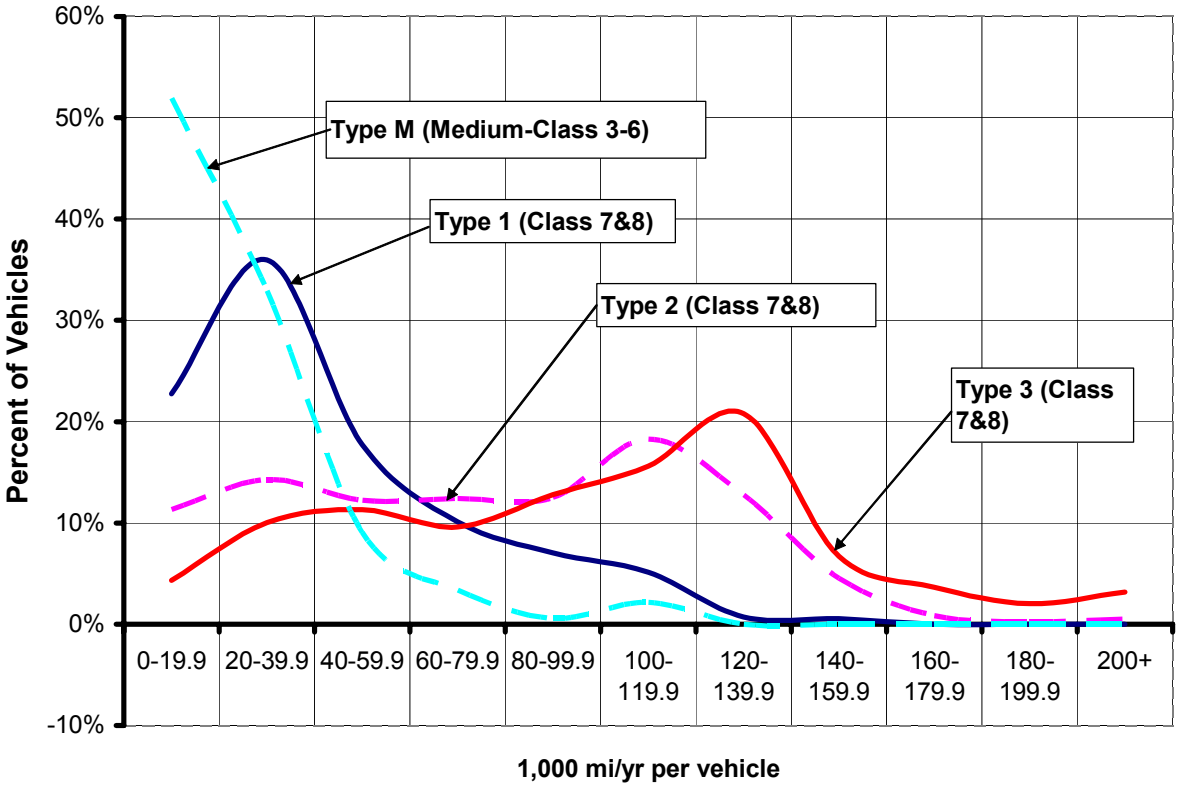

Exhibit 2: Type 1 Vehicle Use

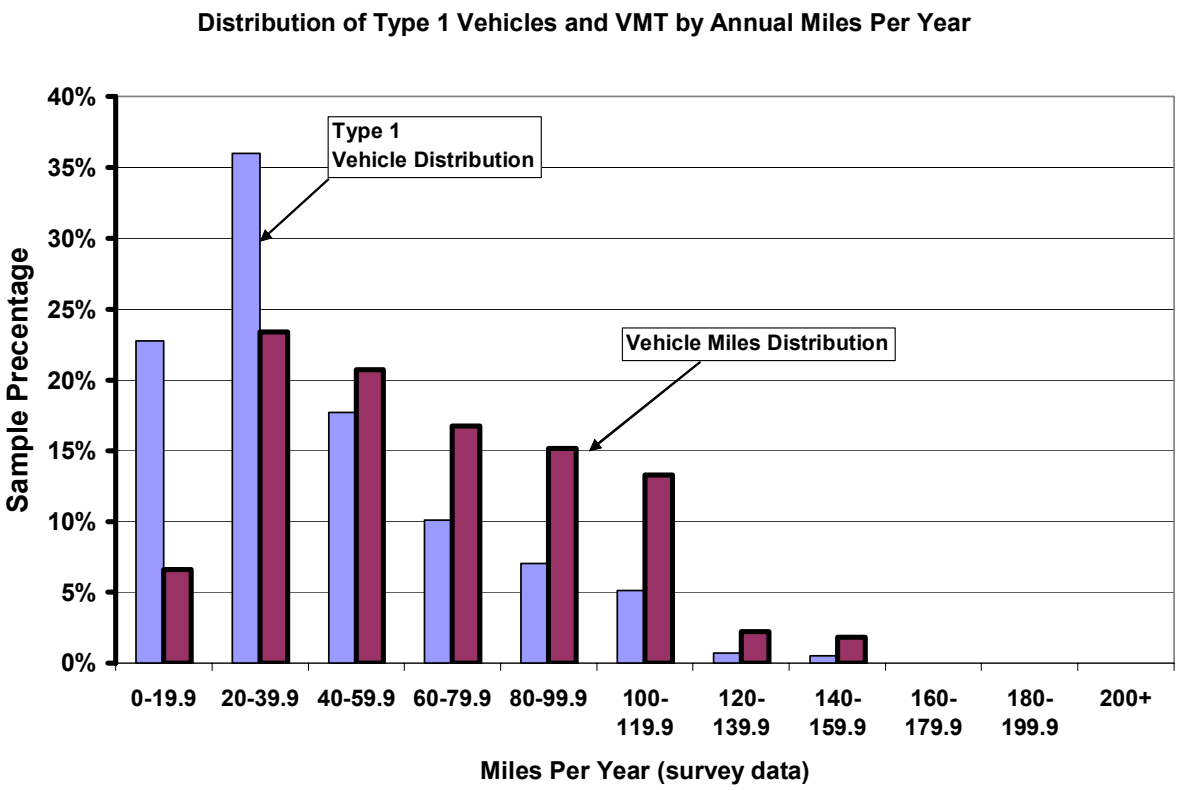

Exhibit 3: Type 3 Vehicle Use

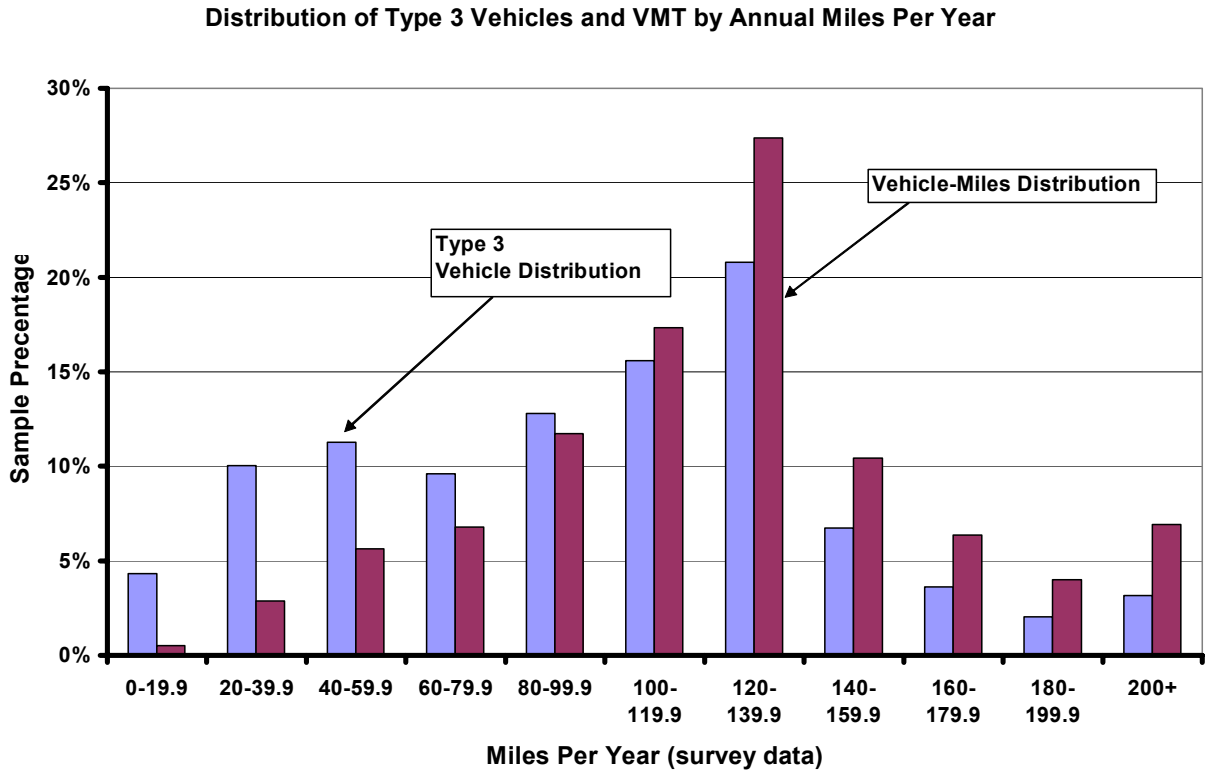

Exhibit 4: Heavy Vehicle Characteristics (1997)

Vehicle Type	Average Annual Miles	Fuel Economy, MPG	Percent Centrally Refueled
Class 3-6	20,126	8.90	40.1%
Class 7 & 8; Type 1	40,043	4.55	59.8%
Class 7 & 8; Type 2	74,066	6.16	41.0%
Class 7 & 8; Type 3	92,434	7.50	42.0%

Exhibit 5: Heavy Truck Benefits Analysis Models

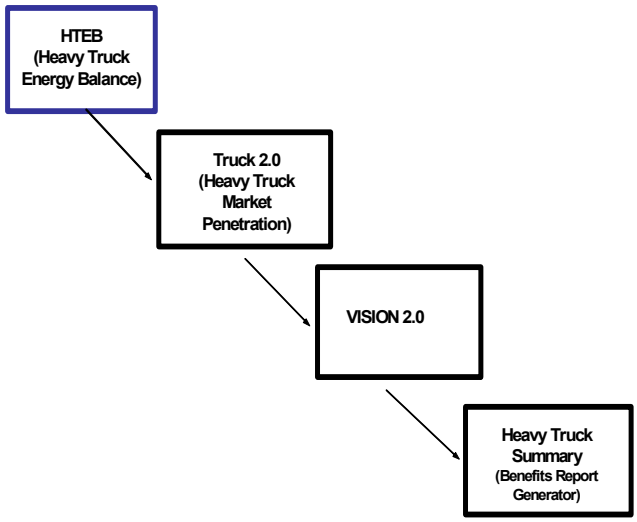

Exhibit 6: Advanced Heavy Vehicle Characterization (New Vehicles)

	Characteristic	2010	2020	2030	2040	2050
1	Fuel Economy Class 7-8, Local, mpg Multiplier	1.26	1.46	1.46	1.46	1.46
2	Fuel Economy Class 7-8, Intermediate, mpg Multiplier	1.35	1.64	1.64	1.64	1.64
3	Fuel Economy Class 7-8, Long-Haul, mpg Multiplier	1.47	1.79	1.79	1.79	1.79
4	Fuel Economy Class 3-6-Hybrid, mpg Multiplier	1.70	1.70	1.70	1.70	1.70
5	Fuel Economy Class 3-6-Non-hybrid, mpg Multiplier	1.20	1.37	1.37	1.37	1.37
6	Class 7-8, Iincremental Cost, $	$ 35,000	$ 15,000	$ 7,500	$ 7,500	$ 7,500
7	Class 3-6 Hybrid, Incremental Cost, $	$ 19,000	$ 5,400	$ 2,700	$ 2,700	$ 2,700
8	Class 3-6 Nonhybrid, Incremental Cost, $	$ 5,400	$ 1,700	$ 1,700	$ 1,700	$ 1,700

Exhibit 7: Example First Cost and Efficiency Schedule for Advanced Technologies

Year	Baseline Vehicle Cost ($)	*Enhancement: Program Portfolio*	
		Diesel Fuel (only)	
		Gross 1st Cost ($)	Efficiency Ratio
2000	150,000	0	1.000
2005	150,000	45,000	1.500
2010	150,000	35,000	1.500
2015	150,000	25,000	1.760
2020	150,000	15,000	1.760
2025	150,000	11,000	1.760
2030	150,000	7,500	1.760
2035	150,000	7,500	1.760
2040	150,000	7,000	1.760
2045	150,000	7,000	1.760
2050	150,000	7,000	1.760

Exhibit 8: ATA Survey Payback Preference Distribution

Number of Years	Percent of Motor Carriers
1	16.4%
2	61.7%
3	15.5%
4	6.4%

Exhibit 9: Truck Payback Algorithm—Type 1 Trucks

Spreadsheet Location	Description	Comments
Column A	**Year**	Identifies year for which values, calcuations and results are representative.
Columns B - F	**Fuel Economy by Technology**	Values are developed based on baseline technology mpg assumptions and efficiency ratios for advanced technologies.
Column G	**Cost of Alternative Fuel in $/GGE**	Links to Fuel Prices Page
Columns H - I	**Calculates annual savings for 2 alternative technologies**	For Advanced Diesel: (VMT(C10)x$/GGE/Baseline MPG - VMT x $/GGE/Adv. Diesel MPG)
Columns J - M	**Calculates Net Present Value of Savings for 'Advanced Diesel'**	Column J: 1 Year, K: 2 years, L: 3 years; M: 4 years
Columns N - Q	**Calculates Net Present Value of Savings for 'Alternative Fuel Technology'**	Column N: 1 Year, O: 2 years, P: 3 years; Q: 4 years
Columns R - U	**If-then Statement to determine 'Cost Effectiveness Factor' (CEF)**	If NPV of savings is > Cost of Technology, cell value is (cost - NPVSavings)/Cost; Otherwise cell value is 0. Columns are for paybacks of 1, 2, 3, and 4 years.
Column V	**Technology purchase cost 'Alternative Fuel Technology'**	Values are linked to Cost values on 'Inputs' page.
Column W - Z	**Repeats calcuations in Columns R through U for 'Alternative Fuel Technology'**	
Column AA	**If-then Statement to determine 'Technology Adoption Factor' (TAF) for 'Advanced Diesel'**	If 'Cost Effectiveness Factor' for Year 1 PB is 0, cell value = 100; Otherwise (100-((exp(1995 CE Factor-Current Yr. Factor) - 1)/10 x 100)
Column AB	**Continuation of TAF Calculation for Year 1 Payback market**	If AA<0, cell value is 1; Otherwise the Value is the same as AA.
Columns AC + AD	**Repeat AA and AB for 2 year payback market**	
Columns AE + AF	**Repeat AA and AB for 3 year payback market**	
Columns AG + AH	**Repeat AA and AB for 4 year payback market**	
Columns AI - AP	**Repeat Columns AA through AH methodology for 'Alt. Fuel Technology'**	
Column AQ	**If-then statement. Start of Market Penetration for 'Advanced Diesel'**	If AB = 100, then cell value is 0; Otherwise cell value is (1/(1+Abvalue/exp(-2 x Col. R CEF for 1 Year PB))
Column AR	**Same as AQ, but for 2 year PB market.**	
Column AS	**Same as AQ, but for 3 year PB market.**	
Column AT	**Same as AQ, but for 4 year PB market.**	
Column AU	**Final, Step 1; Weighted average market penetration for year 1 through year 4 markets weighting factors**	Weighting factors are based on ATA survey results and are listed at the top of Columns AQ-AT.
Column AV	**Final, Step 2: Reduces Market Penetration to account for market penetration of 'Atl. Fuel Technology' and stay below 100% share.**	=+(AU+(1-BA)*AU)/2
Columns AW - AZ	**Same as columns AQ - AT for 'Alterntive fuel technology'.**	
Column BA	**Final, Step 1; For 'Alt. Fuel Tech.', weighted average market penetration for year 1 through year 4 markets weighting factors**	
Column BB	**Final, Step 2: Reduces Market Penetration to account for market penetration of 'Atl. Fuel Technology' and stay below 100% share.**	
Columns BD - BN	**Macro Results Array-Centrally Refueled Advanced Diesels**	Central1 Macro results are printed in this part of spreadsheet
BO	**Final Step 3: 'Advanced Diesel' (Centrally Refueled) Summation of %VMT that is centrally refueled for the VMT range (e.g. 0-19.9k)* % Market penetration for BD - BN array.**	Results are linked to Market Penetration Page
Columns BQ - CA	**Macro Results Array-Centrally Refueled Alternative Fuels**	Macro results are printed in this part of spreadsheet. Alt Fuel technology only competes in Centrally Refueled Segment
CB	**Final Step 3: 'Alt. Fuel' Summation of %VMT that is centrally refueled for the VMT range (e.g. 0-19.9k)* % Market penetration for BD - BN array.**	Results are linked to Market Penetration Page
Columns CD - CN	**Macro Results Array-Non Centrally Refueled Advanced Diesels**	Macro results are printed in this part of spreadsheet
CO	**Final Step 3: 'Advanced Diesel' (Non-centrally refueled) Summation of %VMT that is centrally refueled for the VMT range (e.g. 0-19.9k)* % Market penetration for BD - BN array.**	Results are linked to Market Penetration Page

Exhibit 10: Advanced Heavy Vehicle Market Penetration and Fuel Economy Results for NEMS Modeling

Year	Class 7 & 8				Class 3 - 6			
	Combined Market Penetration, % VMT	Base MPG (VISION) in gasoline equivalent gallons	Fuel Economy for All New Technology Sales, mpg	Fuel Economy Multiplier only for trucks with new techology which achieve the market penetration shown in Column 2	Combined Market Penetration, % VMT	Base MPG (VISION) in gasoline equivalent gallons	Fuel Economy for All New Technology Sales, mpg	Fuel Economy Multiplier only for trucks with new techology which achieve the market penetration shown in Column 6
1	2	3	4	5	6	7	8	9
2005	0%	5.70	10.00	1.75	0%	8.67	11.50	1.33
2006	0%	5.69	10.10	1.78	0%	8.64	11.56	1.34
2007	0%	5.67	10.21	1.80	0%	8.61	11.63	1.35
2008	0%	5.66	10.31	1.82	0%	8.57	11.69	1.36
2009	0%	5.64	10.42	1.85	1%	8.54	11.75	1.38
2010	1%	5.63	10.52	1.87	4%	8.51	11.82	1.39
2011	2%	5.69	10.59	1.86	12%	8.51	11.85	1.39
2012	3%	5.75	10.65	1.85	15%	8.51	11.88	1.40
2013	5%	5.81	10.72	1.84	24%	8.52	11.91	1.40
2014	10%	5.87	10.78	1.84	24%	8.52	11.94	1.40
2015	15%	5.94	10.85	1.83	33%	8.52	11.97	1.40
2016	19%	6.00	10.93	1.82	40%	8.52	12.01	1.41
2017	27%	6.06	11.00	1.82	43%	8.52	12.06	1.41
2018	28%	6.12	11.08	1.81	48%	8.53	12.10	1.42
2019	44%	6.18	11.15	1.81	48%	8.53	12.15	1.42
2020	53%	6.24	11.23	1.80	50%	8.53	12.19	1.43
2021	57%	6.24	11.24	1.80	52%	8.53	12.26	1.44
2022	58%	6.25	11.25	1.80	52%	8.53	12.33	1.45
2023	65%	6.25	11.26	1.80	52%	8.53	12.39	1.45
2024	68%	6.25	11.27	1.80	54%	8.53	12.46	1.46
2025	69%	6.26	11.28	1.80	56%	8.53	12.53	1.47
2026	70%	6.26	11.28	1.80	56%	8.53	12.65	1.48
2027	79%	6.26	11.29	1.80	56%	8.53	12.77	1.50
2028	80%	6.26	11.29	1.80	56%	8.53	12.89	1.51
2029	83%	6.27	11.30	1.80	67%	8.53	13.01	1.53
2030	84%	6.27	11.30	1.80	75%	8.53	13.13	1.54
2031	85%	6.27	11.30	1.80	78%	8.53	13.20	1.55
2032	86%	6.28	11.31	1.80	80%	8.53	13.26	1.55
2033	87%	6.28	11.31	1.80	83%	8.53	13.33	1.56
2034	88%	6.28	11.31	1.80	86%	8.53	13.40	1.57
2035	89%	6.29	11.32	1.80	89%	8.53	13.46	1.58
2036	89%	6.29	11.32	1.80	93%	8.53	13.53	1.59
2037	90%	6.29	11.32	1.80	93%	8.53	13.59	1.59
2038	90%	6.29	11.32	1.80	93%	8.53	13.66	1.60
2039	91%	6.30	11.33	1.80	93%	8.53	13.73	1.61
2040	91%	6.30	11.33	1.80	93%	8.53	13.79	1.62
2041	91%	6.30	11.33	1.80	93%	8.53	13.79	1.62
2042	92%	6.30	11.33	1.80	93%	8.53	13.79	1.62
2043	92%	6.31	11.34	1.80	93%	8.53	13.79	1.62
2044	92%	6.31	11.34	1.80	93%	8.53	13.79	1.62
2045	92%	6.31	11.34	1.80	93%	8.53	13.79	1.62
2046	92%	6.31	11.34	1.80	93%	8.53	13.79	1.62
2047	93%	6.31	11.34	1.80	93%	8.53	13.79	1.62
2048	93%	6.32	11.35	1.80	93%	8.53	13.79	1.62
2049	93%	6.32	11.35	1.80	93%	8.53	13.79	1.62
2050	93%	6.32	11.35	1.80	93%	8.53	13.79	1.62